MECHANICAL DISTORTIONS IN THE ENERGY DOUBLER DIPOLES DURING COOL-DOWN. A POSSIBLE MECHANISM TO INDUCE TORQUES IN THE CRYOSTAT COMPONENTS.*

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Introduction

A serious remaining problem in the superconductive dipoles is the stability of the field direction. The Doubler Design Report sets a limit of less than 0.5 mr for the variation in the field direction. The parameters that may affect this direction are thermal cycles, ramping, quenches and mechanical handling. Starting during October, 1979 a large number of measurements were performed to study these parameters. The data were circulated and discussed then. However, it seems that this information should now be made available to a wider audience. There was evidence then that some of these parameters did affect the field direction more than the required tolerance.

It was observed at the time that large mechanical distortions of the magnet's yoke took place during cool-down. The purpose of this note is to summarize these particular results and discuss the torques induced in the cryostat's components by the mechanical distortions.

Mechanical Distortions

At the Magnet Test Facility, stand #1 was made available for long term studies of the Vertical Plane stability. All the data for the mechanical distortions was obtained for magnet TA0216. This magnet

*Due to the renewed interest in the Vertical Plane problem, this is the first of a series of TM's reviewing data taking when the problem was assumed to be solved.

was hand-fitted with one of the "old" design conical anchors. The anchor was individually fitted so that a firm coil support was expected even at low temperature.

In addition to the normal instrumentation for Vertical Plane measurements, both A.C. and D.C., the magnet was instrumented with dial gauges to observe variations on the yoke shape with respect to the test stand. A sketch of the set-up is included in Figure 1.

After a given cool-down was started, at various time intervals the reading of the dial gauges was recorded. Under the assumption that no large distortions of the stand itself were present, the yoke was seen to distort around the two support points. The upstream and downstream end of the yoke tilted downwards and the center section of the yoke was raised. This distortion disappeared as thermal equilibrium within the magnet was reached except for some residual distortions of the order of less than 0.002". We will assume this to be an estimate of the systematic errors.

Some of the dial gauges were located to measure relative movements between the warm part of the cryostat and the yoke itself. During the mechanical deformations observed, no relative movement in excess of 0.002" was observed, either longitudinal or rotational, between the cryostat and the yoke.

Figure 1 represents the distortions observed during a "normal" cool-down. "Normal" means the same conditions used by M.T.F. to cool-down a magnet for production measurements, or a liquid nitrogen flow of 500 SCFH and full flow of liquid helium. The total cool-down time under these circumstances is of the order of 4 hours. Cooling proceeds from the downstream end first, and this end starts to dip first. The data for the middle section is plotted with the sign reversed. The middle section and the upstream end distort at the same

time, but the disappearing of the distortion is last at the upstream end. At the worst point, the total distortion of the yoke reaches a total of 0.080". In the next section we will discuss the forces necessary to produce these movements.

In Figure 2, cool-down proceeded in two steps: first, liquid nitrogen; second, liquid helium. The idea was to lengthen the cooling time and determine what part of the cryostat was driving the distortions. The flows utilized for each step were the same as for the "normal" cool-down. The total time for this cool-down was of the order of 7.0 hours. The pattern of distortions is similar to the one of Figure 1. The largest distortions seem due only to the liquid nitrogen flow, although significant ones are also present during the liquid helium step. The nitrogen induced distortions are more than a factor of 2 larger than the helium ones.

In order to minimize the stress in the yoke, a third cool-down was performed. Both the liquid nitrogen flow (down to 100 SCFH) and the liquid helium flow were reduced to what was thought to provide the lowest constant flow conditions. Cool-down required of the order of 9.5 hours. To achieve lower cooling rates some cryogenic modifications at M.T.F. may be required. The distortion pattern repeats itself, although no data was collected for the middle section of the yoke. The magnitude of the distortions is lower by a factor of 2 than the ones during a "normal" cool-down. For this set-up two dial gauges, 14" apart, were located at each of the downstream and upstream ends. Rotations, ot twists, of the yoke could then be measured during the vertical de-formation. These data are presented in Figure 4. A systematic twist of the yoke seems to accompany the vertical movement, with a residual effect of between 0.002" and 0.003" in the same direction for both ends.

One possible mechanism for inducing the very large distortions observed would be the presence, during a cool-down, of vertical thermal gradients in the different cold layers of the cryostat. For example, accumulation of liquid nitrogen at the bottom preferentially could induce such a gradient. For the liquid helium this seems more improbable due to the large mass of the collared coil and the low heat capacity of helium. The large value of the deformations observed makes one wonder about the possibility of mechanical failure of components and welds when the exercise is repeated many times.

Evaluation of the Forces Involved

Hanson and Leininger (TM-891) have studied the vertical deformations of the Energy Doubler Dipoles under their own weight. We will use their results to obtain a value for the forces required to induce the observed vertical deformations during cool-downs.

If a dipole would be suspended by its ends, under its own weight of 8400 lbs., it will deform vertically at the center by 0.180". The weight of the magnet is uniformly distributed along its length. We will assume that the forces transmitted from the inner layers of the cryostat to the yoke by the nine locations of the supports are also equally distributed. As in the worst case above, Figure 1, resulted in a total deformation of 0.080", we scale the magnet's weight to:

$$(8400 \text{ lbs.} \times 0.080")/0.180" = 3733 \text{ lbs.}$$

as the force required to distort the magnet by the liquid nitrogen shield. Equally, for the case in Figure 2, we obtain a force of the order of 1400 lbs to produce the deformation of 0.030" induced by the liquid helium only. See Figure 5.

Mechanism to Induce Torques

During assembly of the cryostats in the yoke a sagitta of 0.26" is introduced in the horizontal plane. It has been suggested that the

horizontal sagitta in combination with the observed mechanical deformations could induce asymmetric forces resulting in a net torque. We have attempted to represent this idea in a simplified form in Figure 6. The horizontal sagitta is shown, as well as the forces driving the vertical distortions concentrated in three places.

Numerical Evaluation of the Torque

We will attempt a rough numerical evaluation of the torques present due to the vertical deformations. As the center of the magnet is forced upwards and the ends are forced down, we will assume that the uniform forces of Figure 5 are concentrated in three locations, as indicated in Figure 7. If the sagitta over the entire length of the magnet is of 0.26", then at 98.5" from the magnet center it should be of the order of 0.159" (we have assumed the magnet being in the form of an arc of a circle in the horizontal plane).

For the case of liquid nitrogen we obtain a torque of:

3733 lbs x 0.159" = 594 in-lbs = 49.5 f-lbs

and for the case of liquid helium:

1400 lbs x 0.159" = 233 in-lbs = 18.6 f-lbs

These torques will be present in the nitrogen shield and in the single and double phase regions of the cryostat respectively if they are driving the vertical deformations. In addition, as the collared coil is being driven into deformation by the liquid nitrogen shield, the resulting torque should be added to the 18.6 f-lbs calculated above.

Using a set of measurements of the collared coil deformation under its own weight and following a similar procedure as above, we calculate that for a distortion of 0.080" and a sagitta of 0.159" a torque of the order of 182 in-lbs (or 15.2 f-lbs) extra should be present in the coil package.

Conclusions

Surprisingly large mechanical deformations were observed during cool-downs of Energy Doubler Dipoles. These deformations can be driven by either the liquid nitrogen shield or the liquid helium parts of the cryostat.

The torque present in the liquid nitrogen shield could have been responsible for the large rotations observed in them, previous to being attached to the cryostat warm tube. The new design should be checked for mechanical stability under these torques.

A possible maximum torque of 405 in-lbs could be present during "normal" cool-down on the collared coil assembly. It is possible that this torque could distort the coil assembly or put undue stress on the anchor; either effect resulting in a rotation of the average field direction.

As cooling progresses from one end of the magnet, the suspensions get unloaded sequentially along the magnet's length. Under the presence of torques this could result in rotations that are not symmetric with respect to the anchor point.

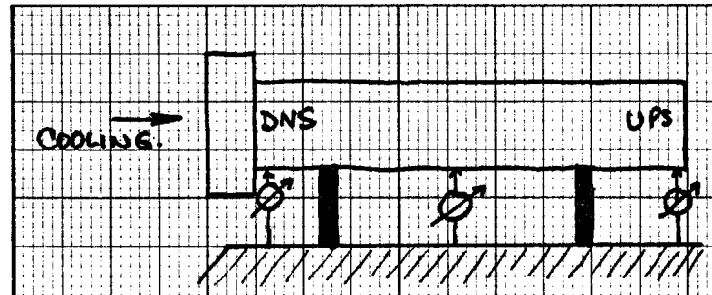
What mechanical failures could result from the repetitive flexing of the magnets vertically should be investigated.

Although the numerical values here given for the torques are very rough, they are sufficient to investigate the rigidity (torsional) of the coil package and of the newly designed anchor.

A possible way of eliminating the large vertical thermal gradients would be to modify the present concentric channels for liquid nitrogen and two phase helium into helical channels by introducing helical dimples on the respective outer tubes.

C. HOSWAT
T.H.

FIGURE 1



MAGNET TA0216
NORMAL COOLDOWN (#2) LN_2 500 SCFH

UPS
MIDDLE x -1
DNS

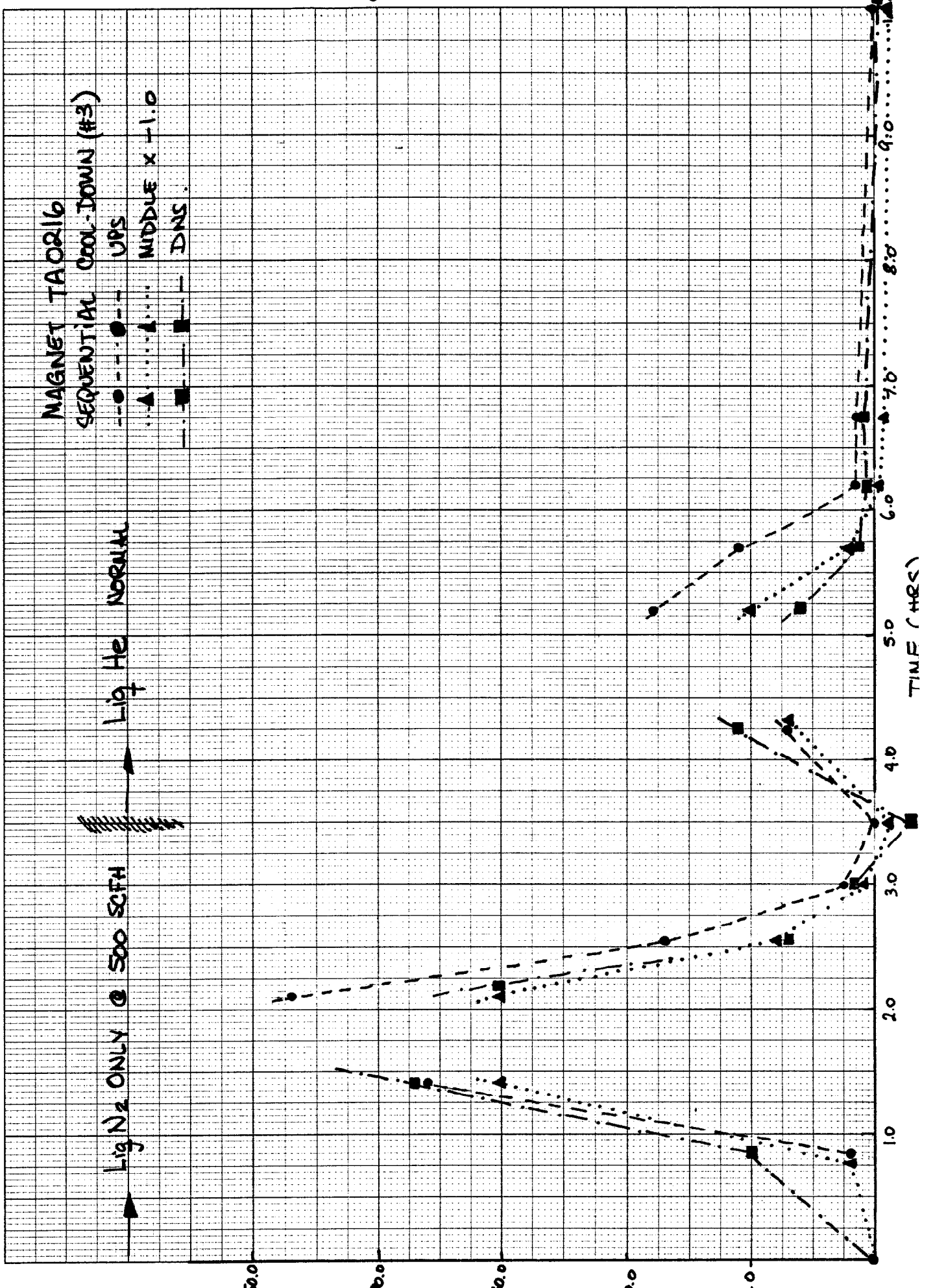
50.0
40.0
30.0
20.0
10.0

1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0

TIME (HRS)

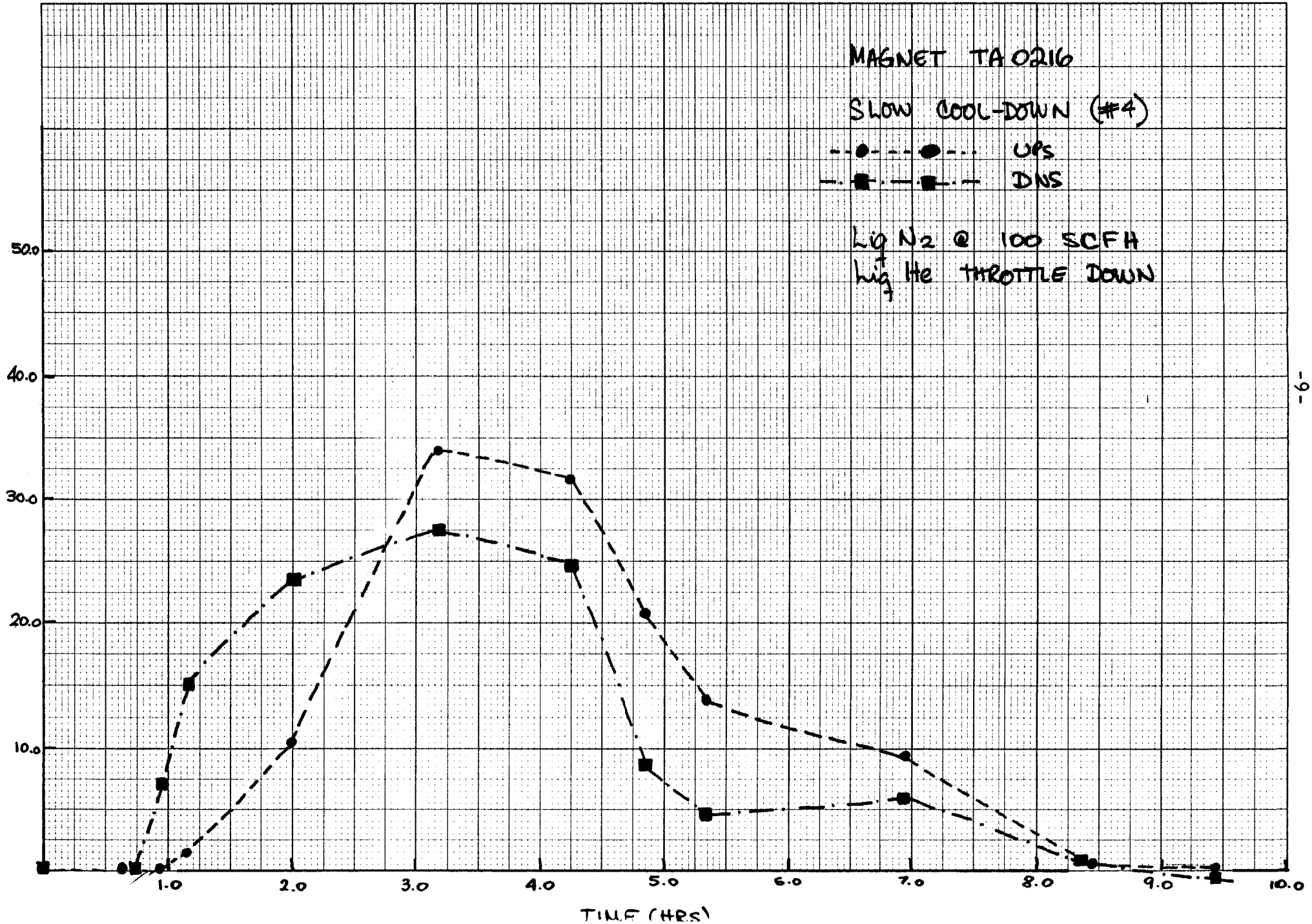
C. HOGAT
TM

FIGURE 2



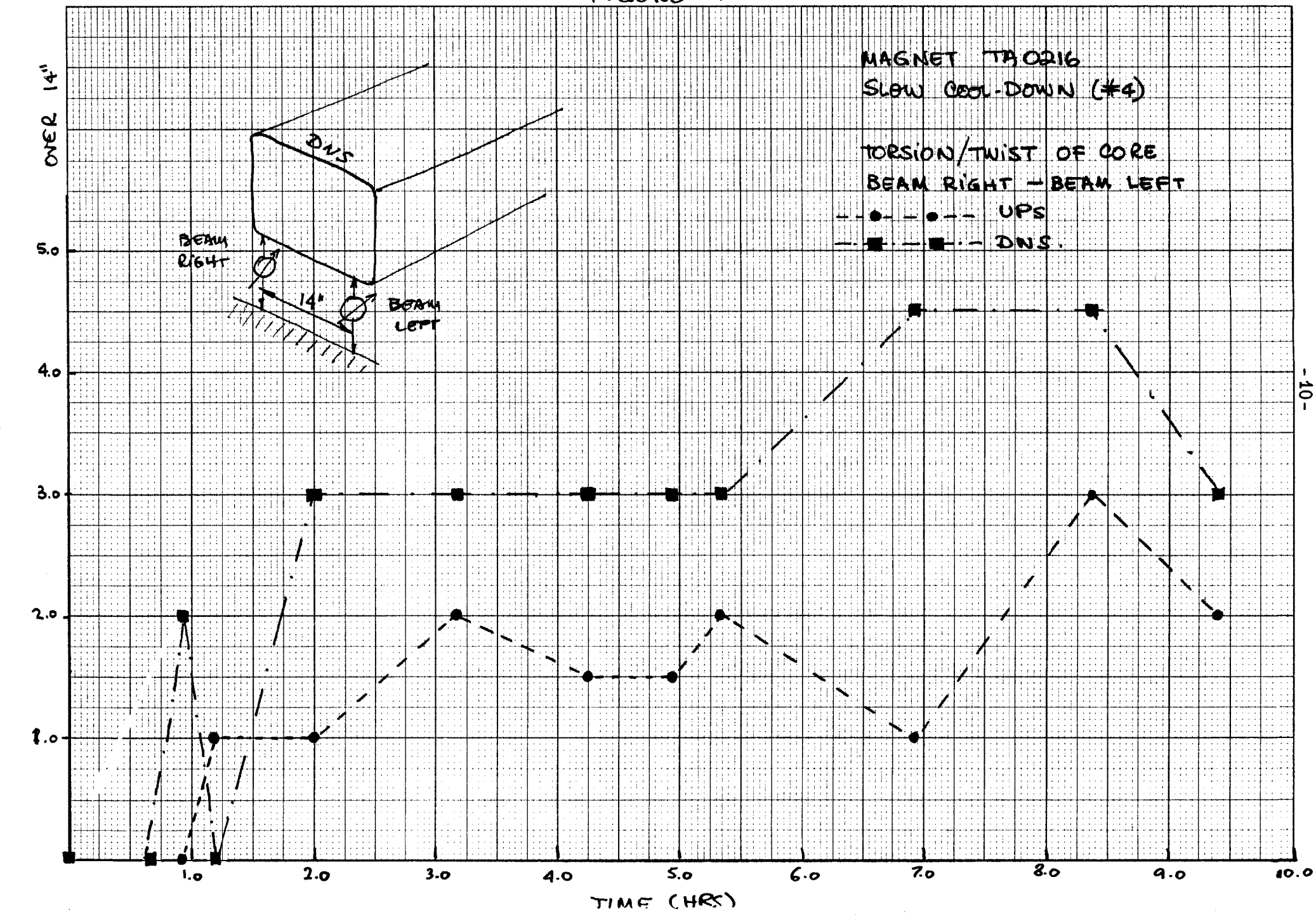
C. HOSNAT
TM

FIGURE 3



C. HOSVAT
TM

FIGURE 4



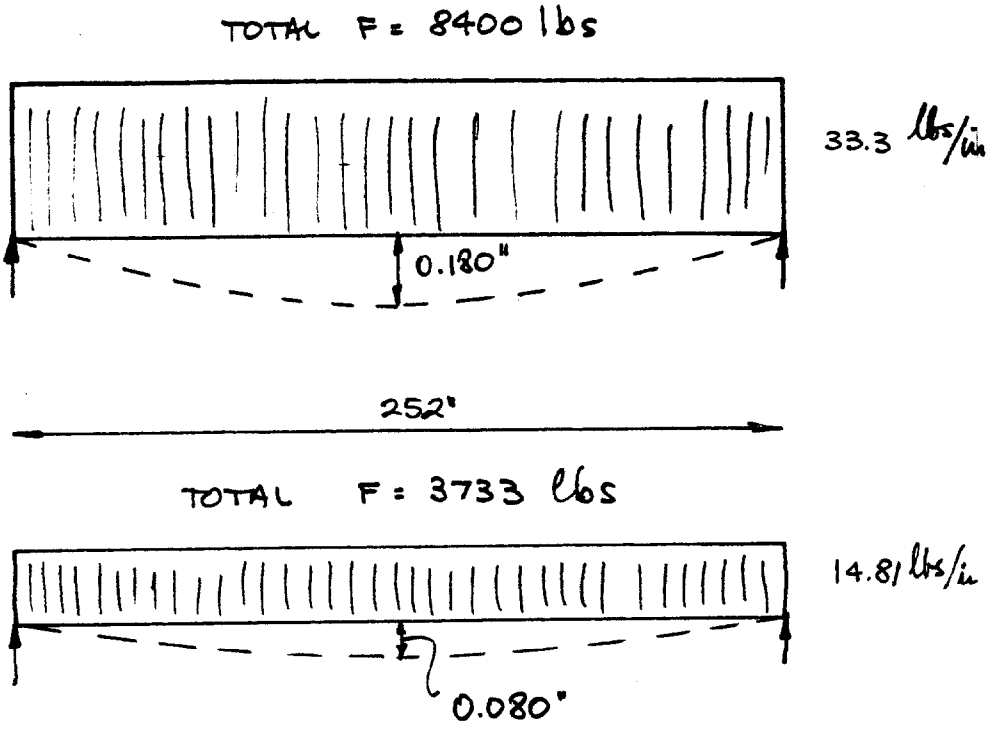


FIGURE 5

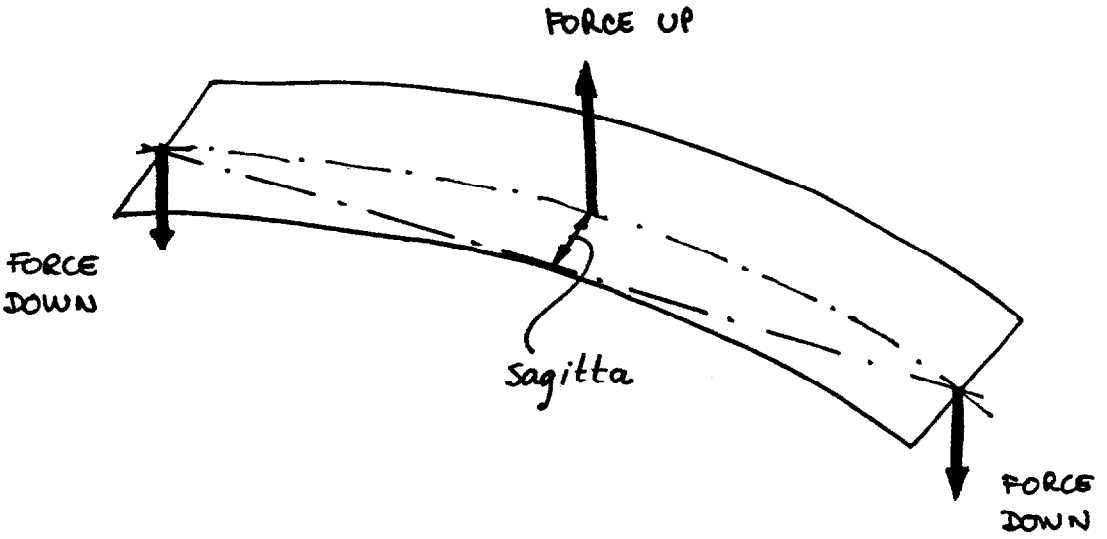


FIGURE 6

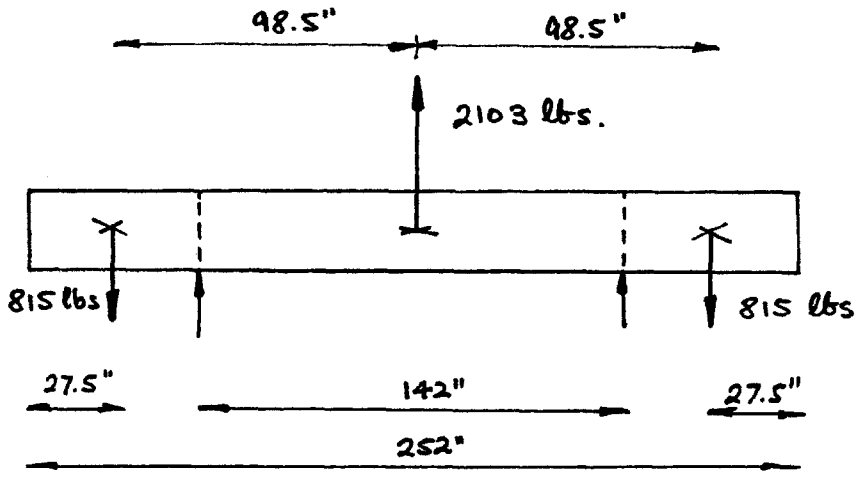


FIGURE 7